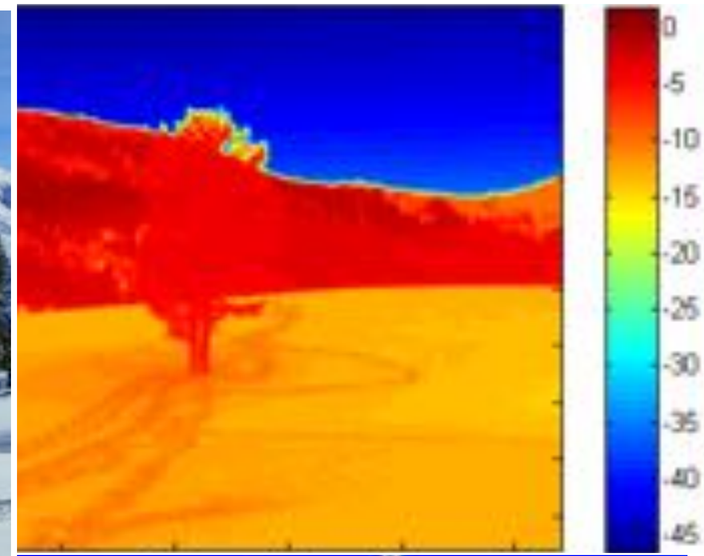
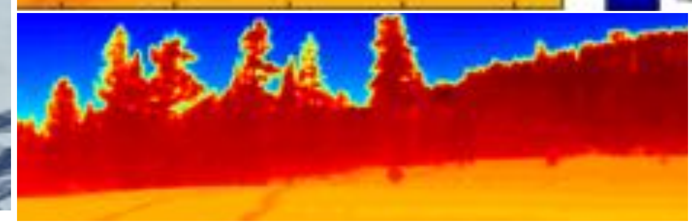
Learning to see in thermal infrared: Surface temperatures of snow and trees





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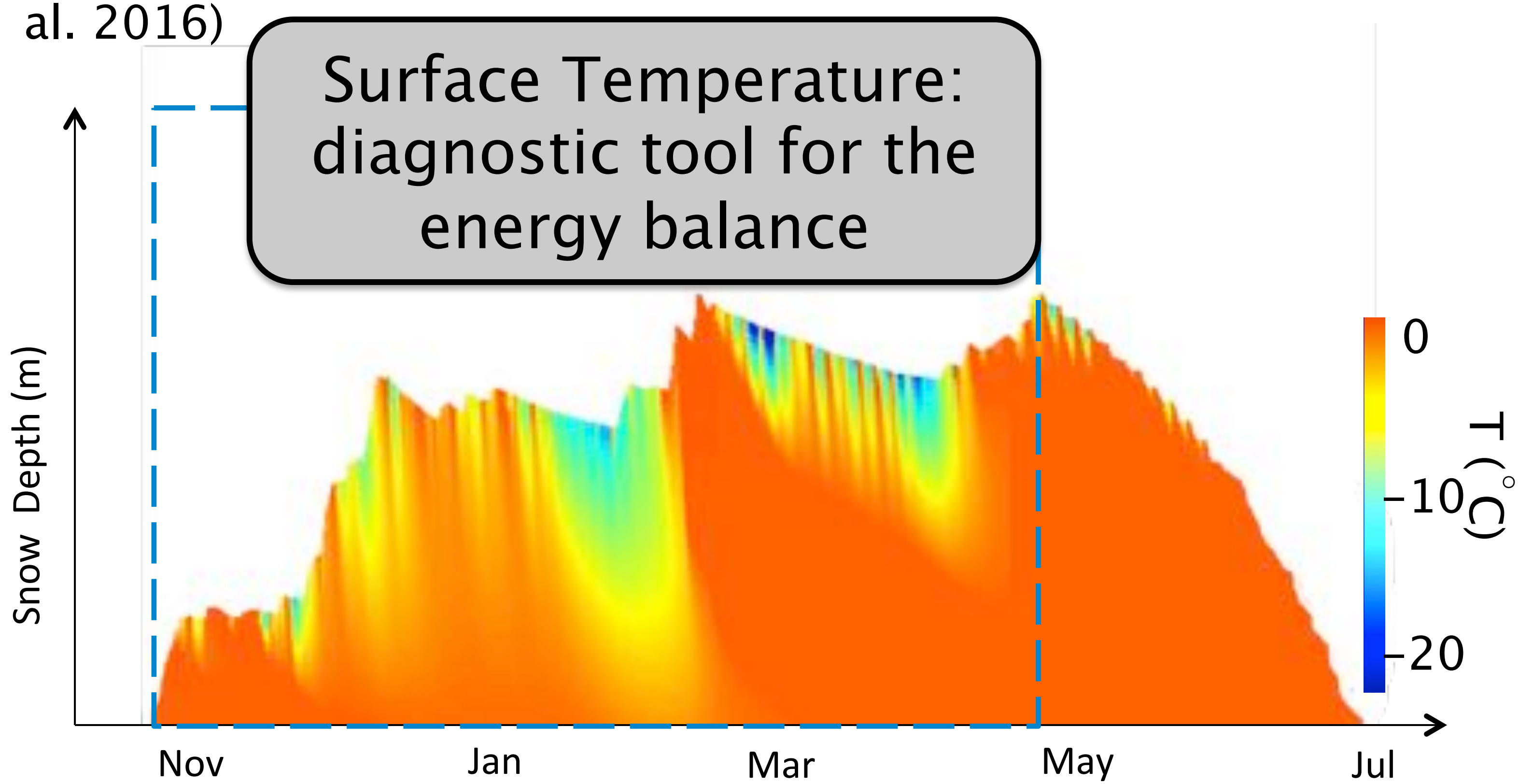
August 10, 2017

Photo by Ryan Currier

Why IR?

- Already measured remotely (on lots of satellites, MODIS, Landsat, ASTER, etc.)
- IR cameras can be mounted on an airplane
- Use T_s to assess model energy balance during non-melt periods (Raleigh et al. 2013; Lapo et al. 2015; Pomeroy et al. 2016)



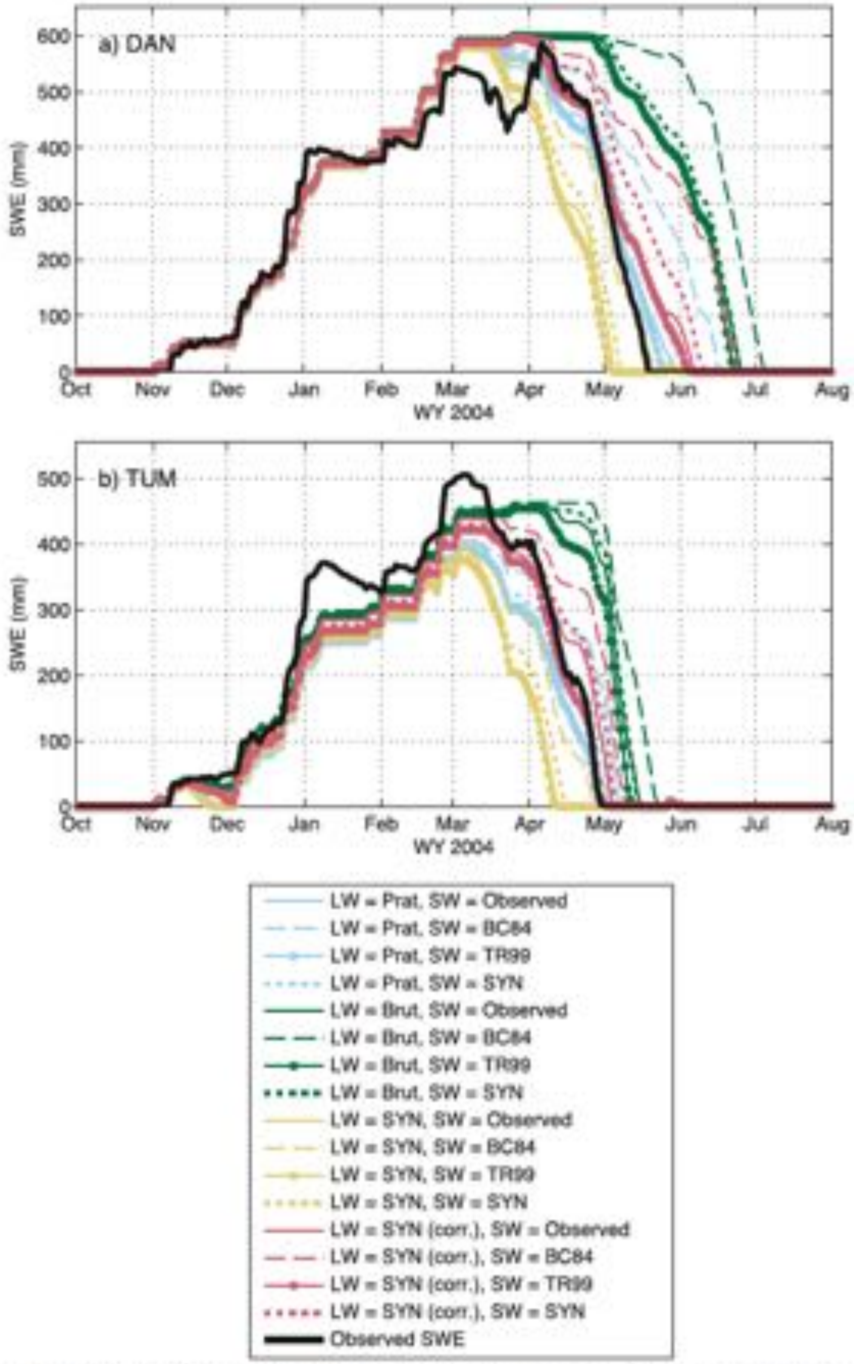


FIG. 5. SWE at (a) DAN and (b) TUM for the 2004 melt season from observations and DHSVM simulations. Results for all combinations of SW and LW irradiance inputs are shown.

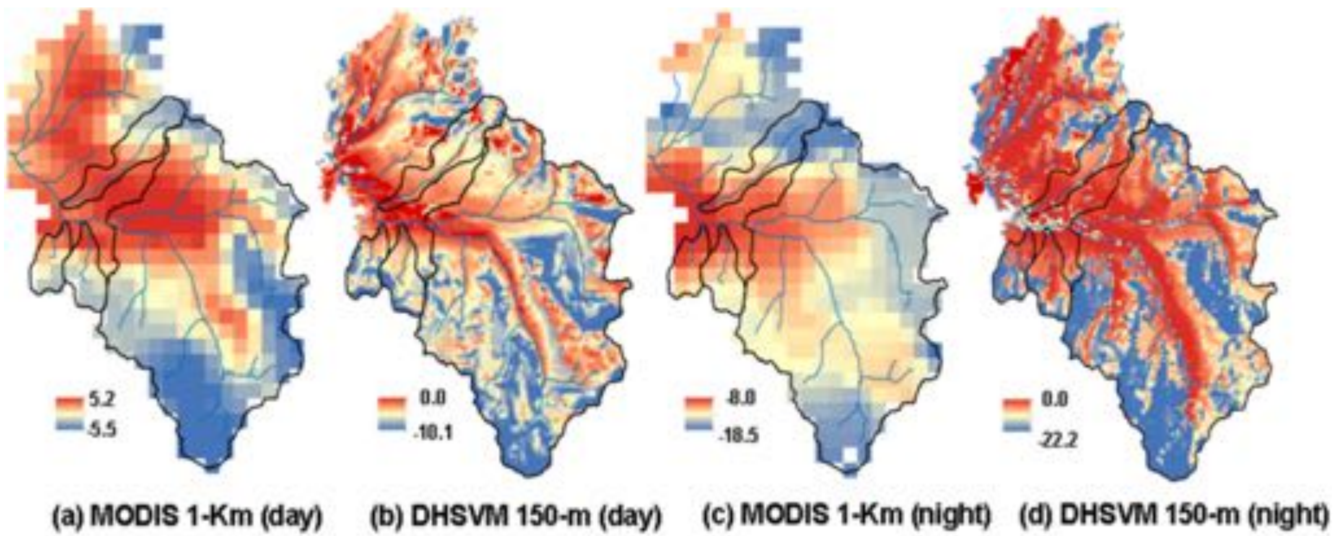
Huge (~2 month) variation in melt timing due to longwave input. Snow surface temp can identify correct longwave.

From Hinkelman et al. 2015, *J. Hydromet.*

Colors are different longwave sources, line-style variations are different shortwave sources.

Dana and Tuolumne snow pillow sites from Tuolumne Watershed, Sierra, CA are shown.

Goal: We'd like something multiple times per day (like MODIS, VIIRS) that gives us information about processes we care about



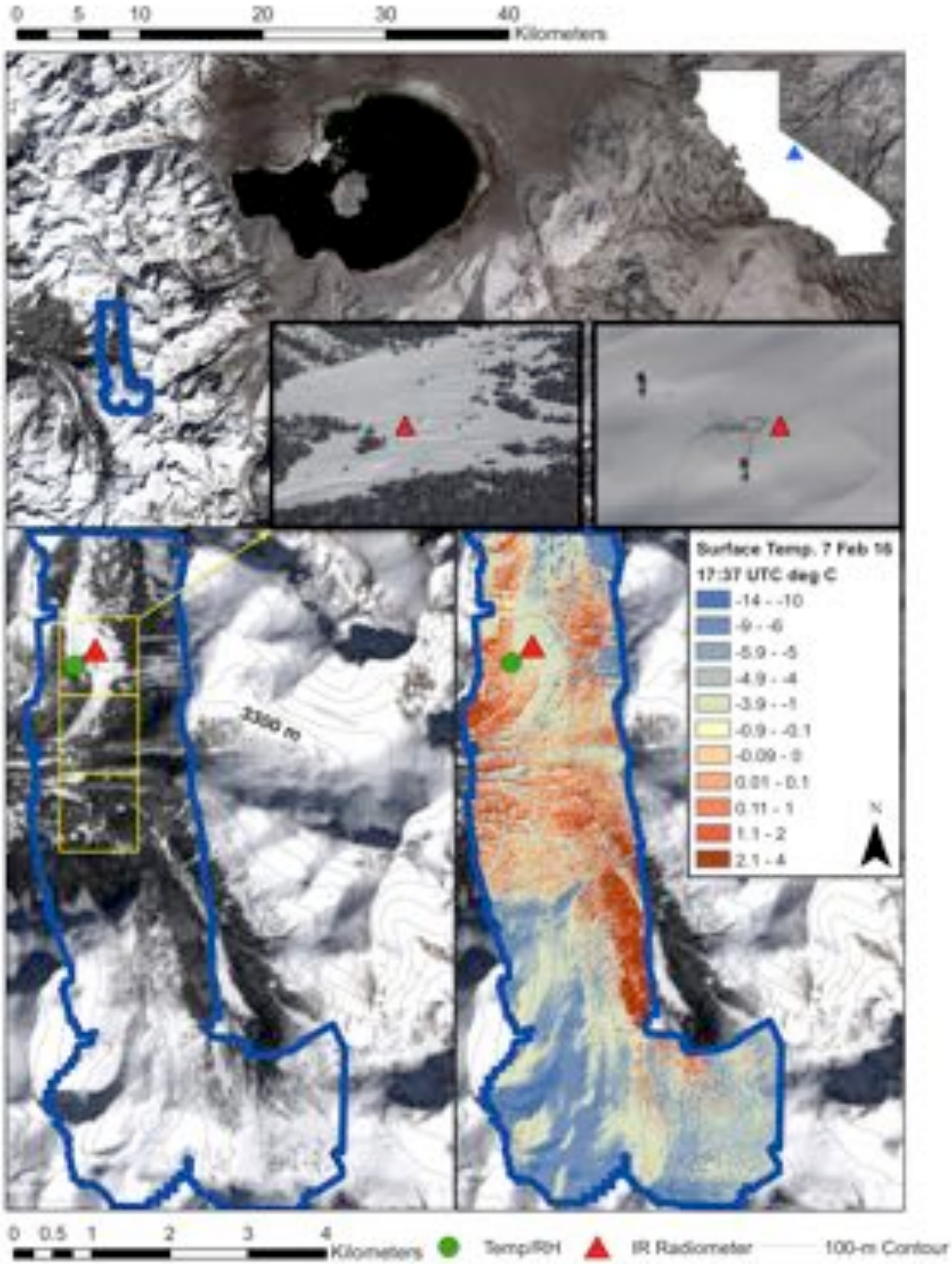
- What does a 1 km grid cell surface temperature really represent?
- How can we make sense of it in terms of the variables we measure and model?

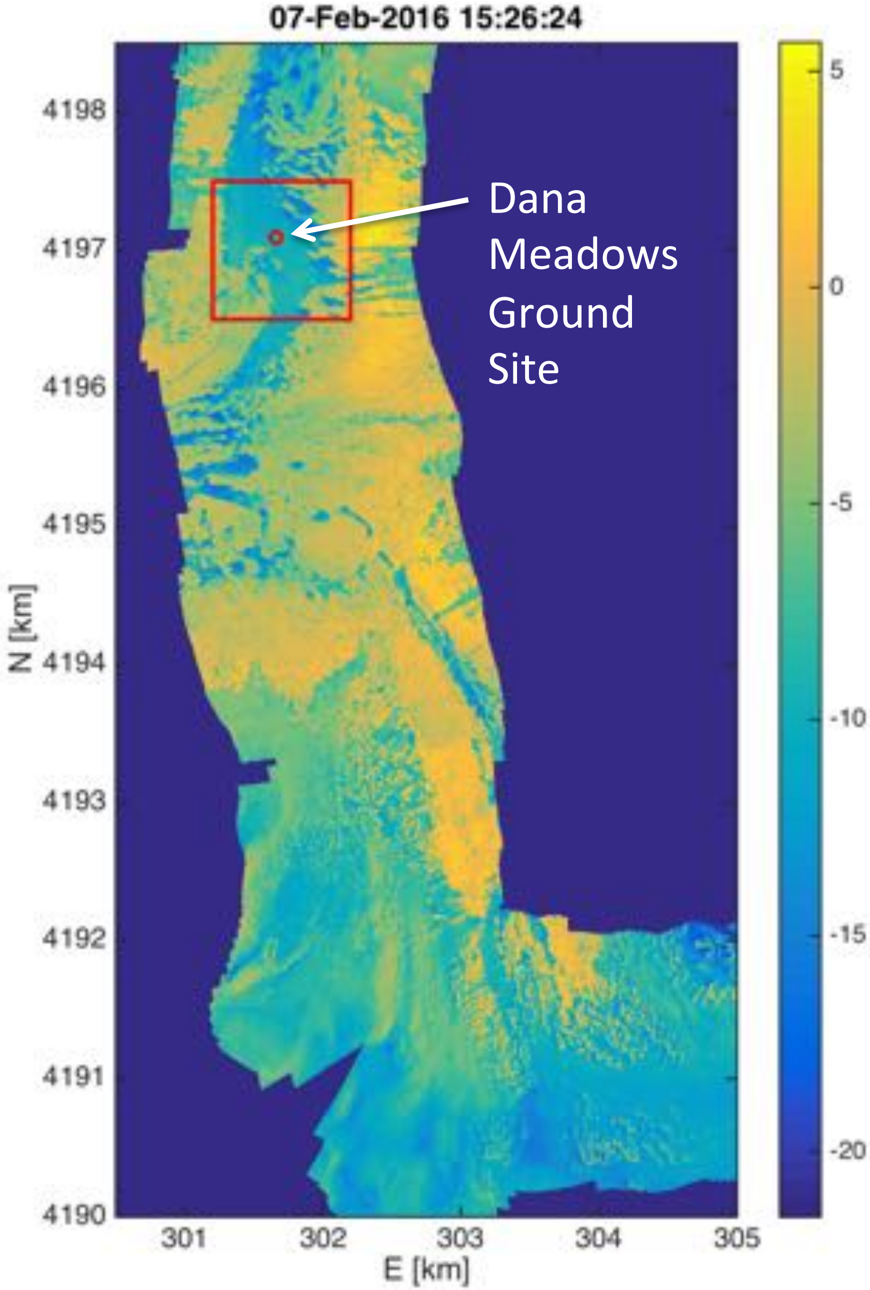
Field Experiment

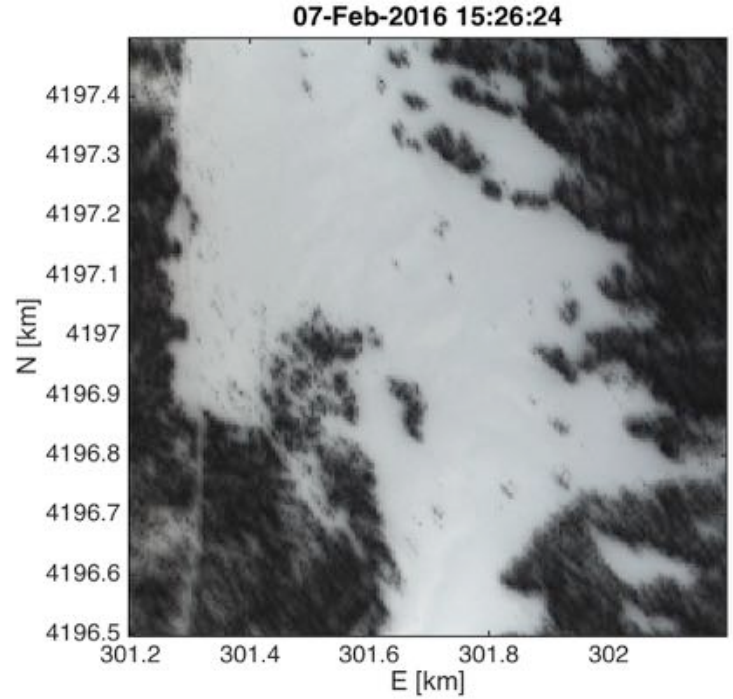
5-8 Feb 2016

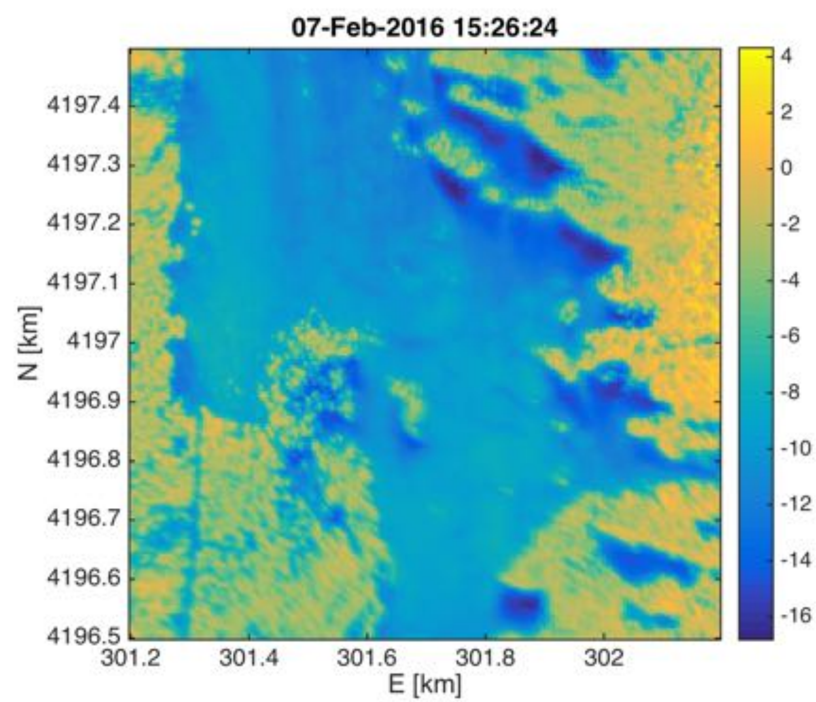
Dana Meadows,

Yosemite, CA







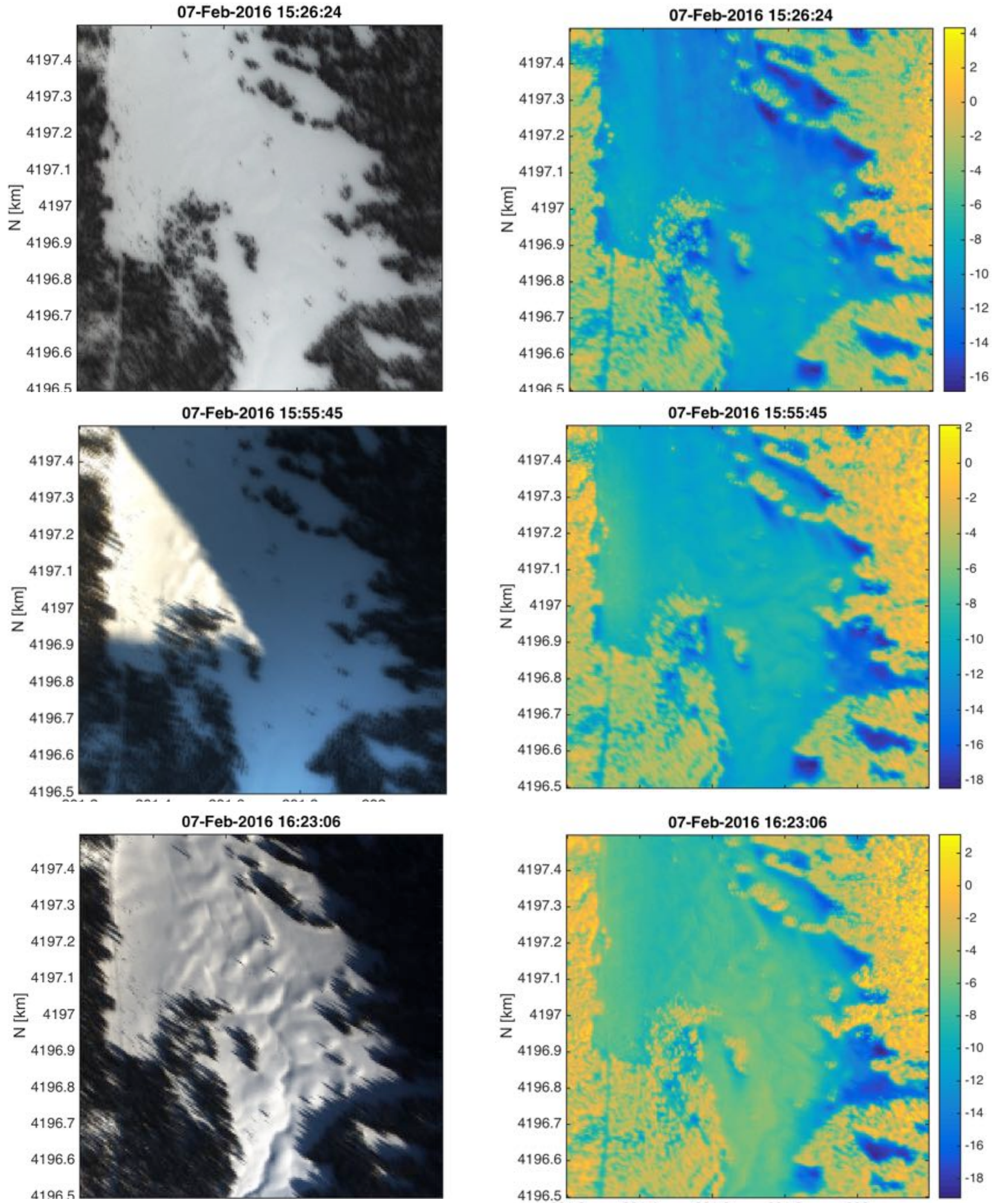


Showing 1 km x 1 km box (~ MODIS pixel size)

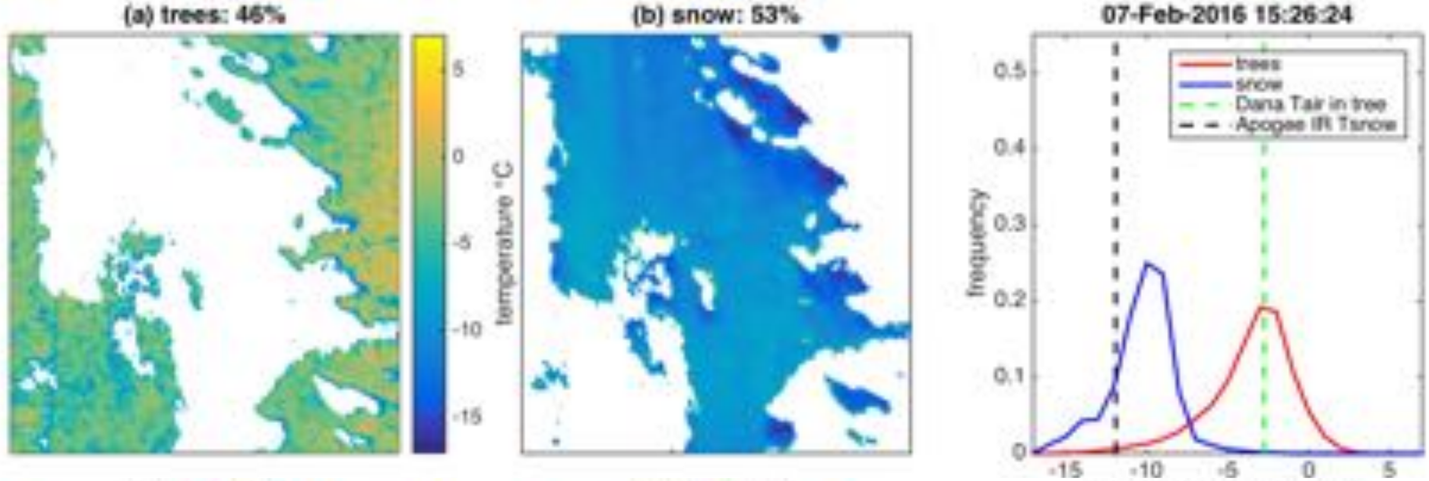
Before sun hits the meadow

Sun just hits the meadow

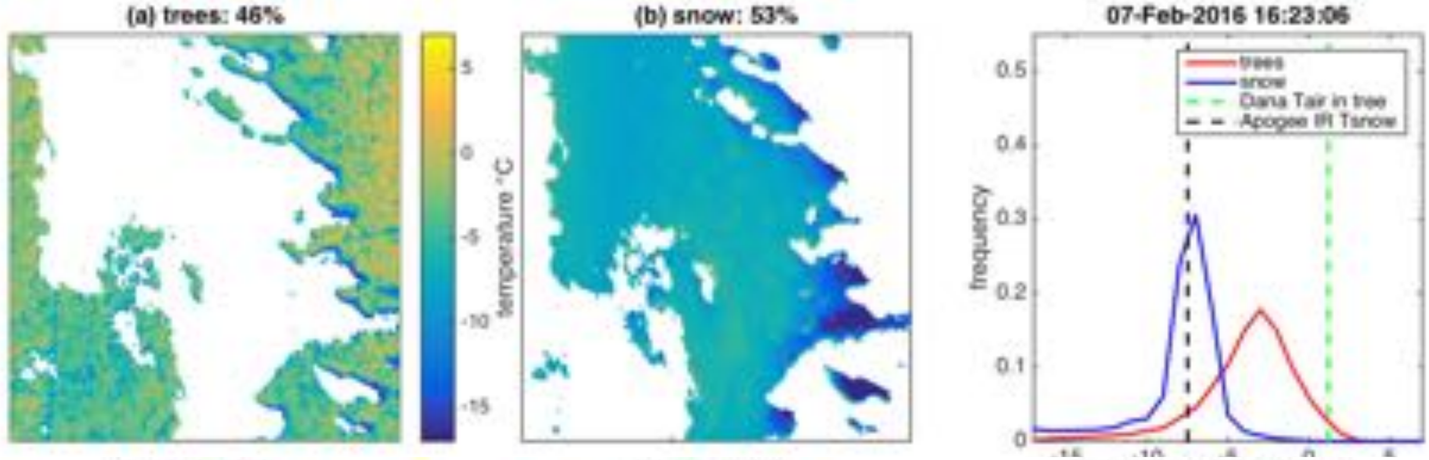
Sunny meadow with shadows



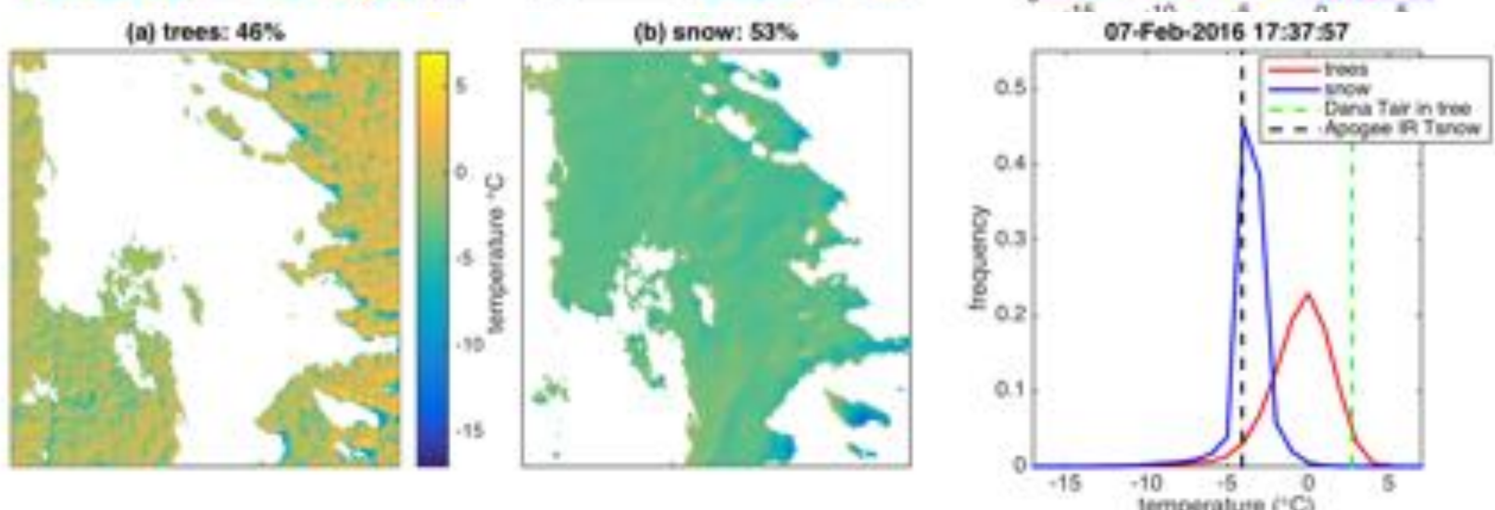
Before sun hits the meadow; Warm wind from the N, coldest spots downwind of trees



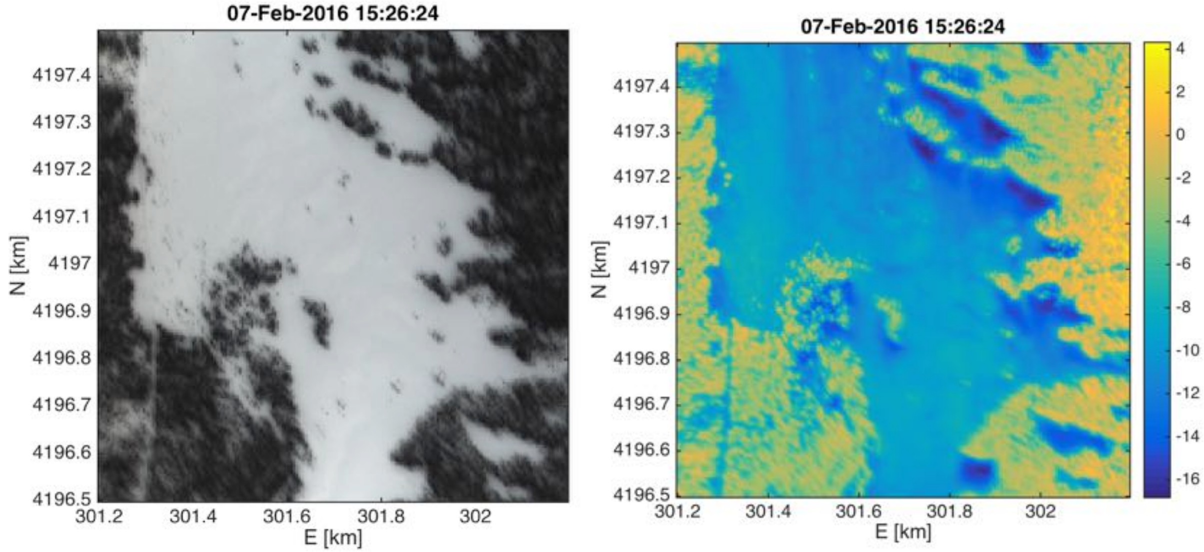
Sun just hits the meadow; coldest spots in shadows northwest of trees



Sunny meadow; Snow surface warms faster than trees



Looking at a 1 km grid cell:



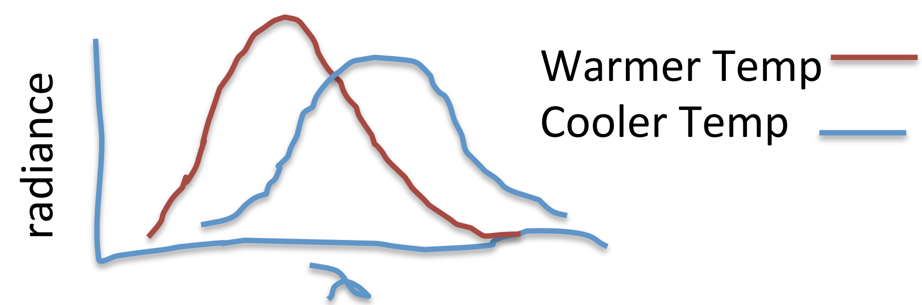
- A main source of uncertainty in remote sensing of snow surface temperature is the mixed pixel problem – we always have snow + something else (here, trees) – the temperature differences between these groups are large (> 5 K)

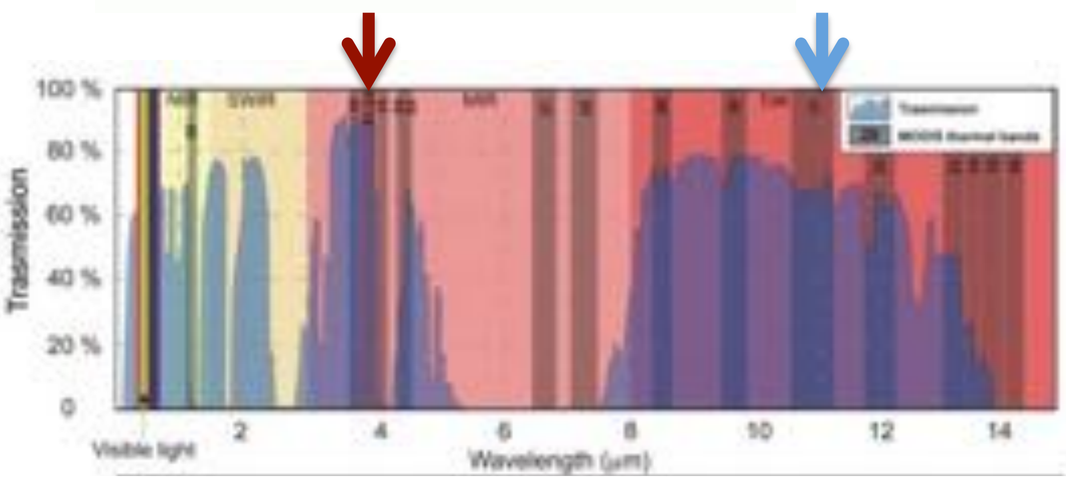
Remote Sensing Secret:

Real remote sensors ignore the Stefan-Boltzman equation ($E = \varepsilon\sigma T^4$) and love the Planck equation instead.

Planck Equation for Irradiance with a given Brightness Temperature, T

$$\beta(\lambda, T) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{\frac{hc}{\lambda kT}} - 1}$$



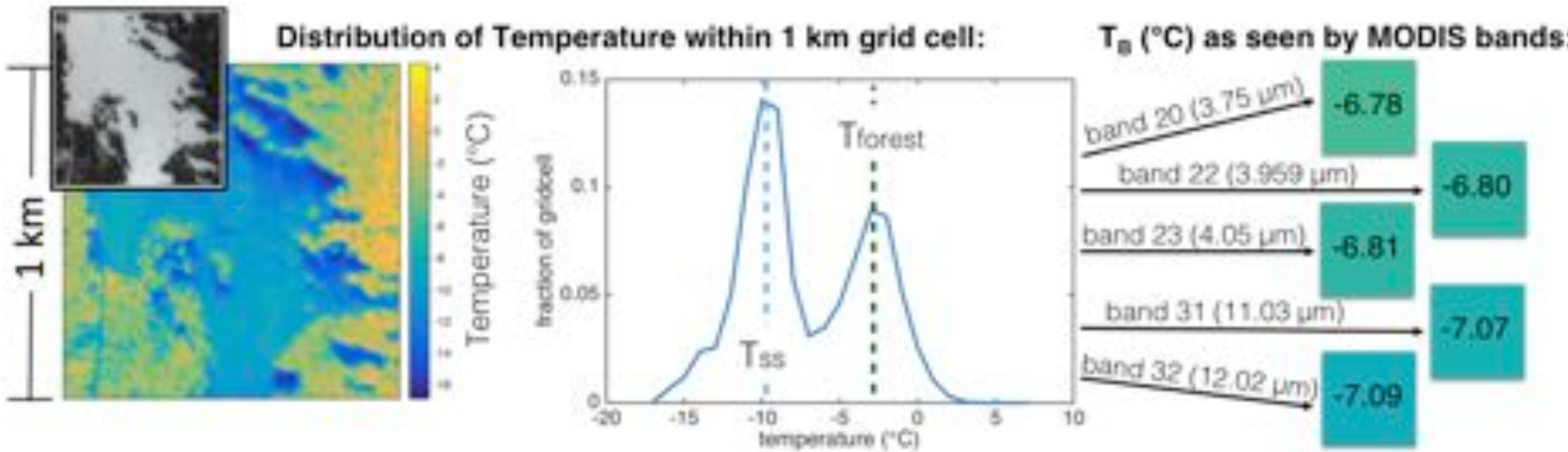


REMOTE SENSING OF ENVIRONMENT 11 221–229 (1981)

A Method for Satellite Identification of Surface Temperature Fields of Subpixel Resolution

Dozier 1981: If you have two temperatures in a pixel, you can use the differences between radiance at multiple wavelengths to determine both temperatures.

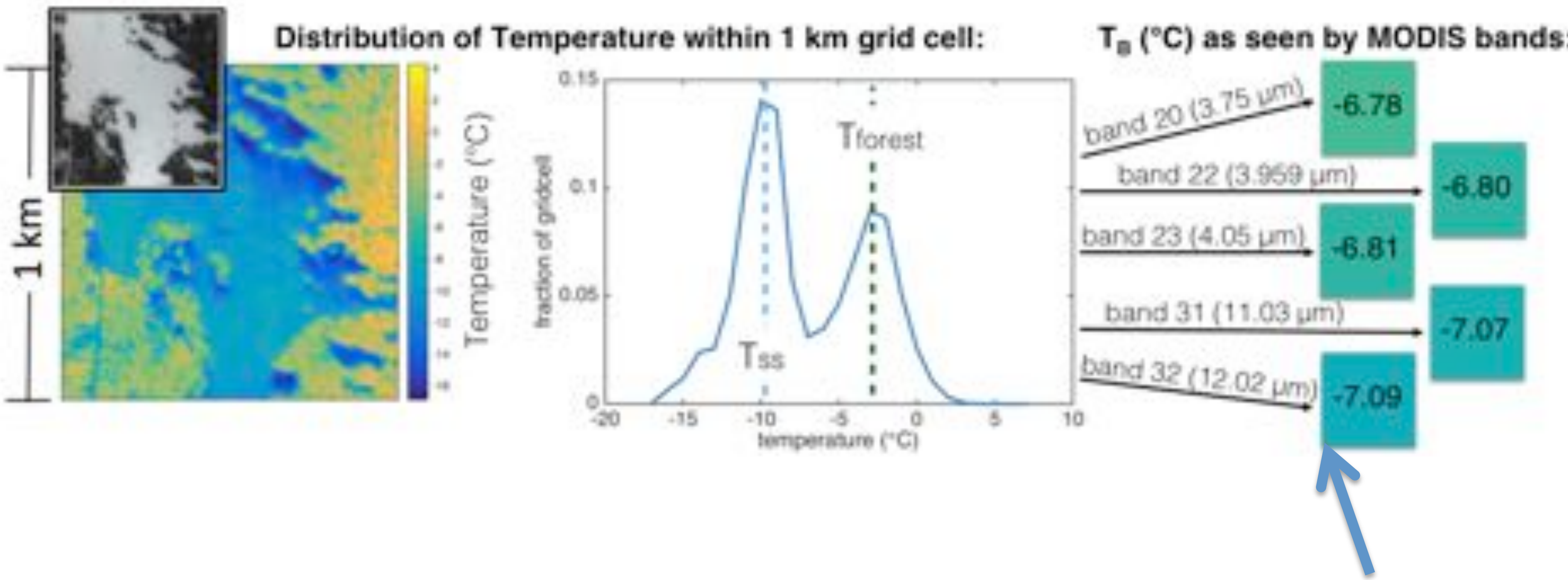
We can separate snow and tree temperatures with multispectral sensing



- Sum Planck's equation over the area at each temperature and invert to get T_B.
- Use nonlinear optimization to fit two values + f_{SCA}.
- 5 equations, 3 unknowns, with simulated data, recovers the modes of the histogram well.

$$L_j = f_{SCA}\beta(\lambda_j, T_{snow}) + (1-f_{SCA})\, \beta(\lambda_j, T_{forest})$$

Small problem…



- The differences between these temperatures are tiny!
- Only differences between the midwave bands and the longwave bands are greater than the sensor noise…
- Essentially, 2 equations, 3 unknowns…

$$L_j = f_{SCA}\beta(\lambda_j,T_{snow}) + (1-f_{SCA})\ \beta(\lambda_j,T_{forest})$$

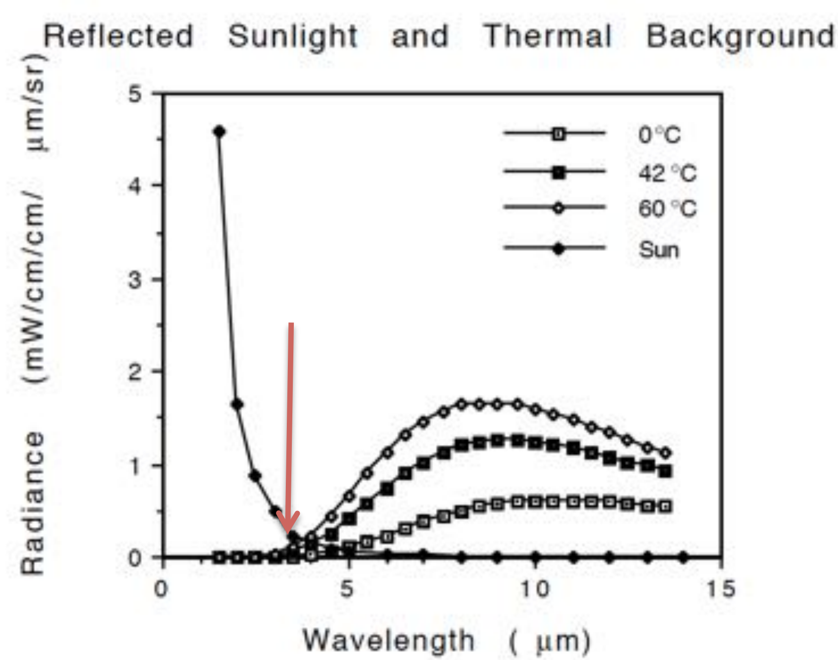
Small problem(s) continued…

NIGHT

- **It's dark**
- **No way to know fSCA**
- **Can't use land surface cover maps because viewing geometry is always changing and pixels are hard to geo-locate**

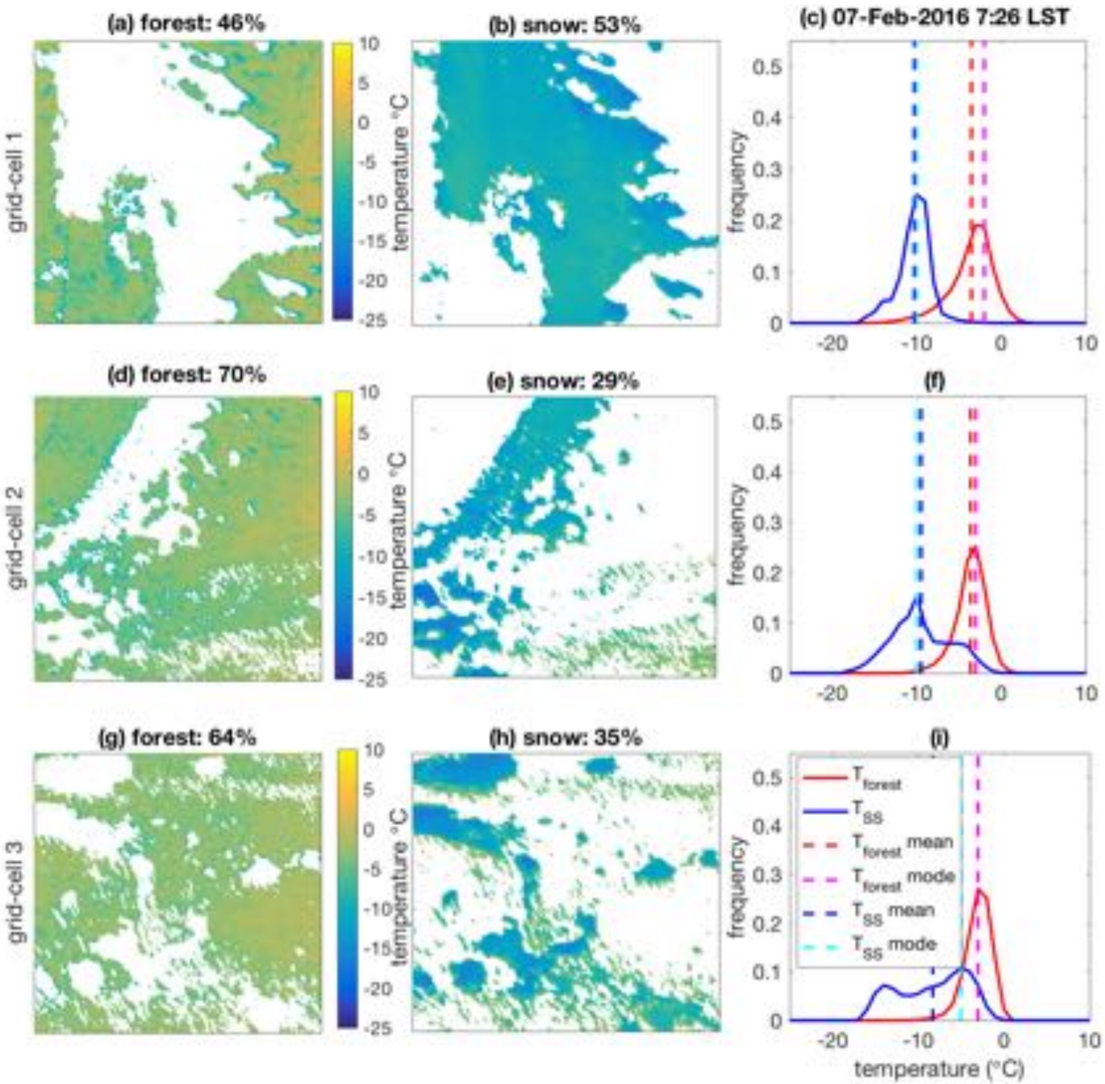
DAY

- **Midwave bands are contaminated by reflected sunlight**



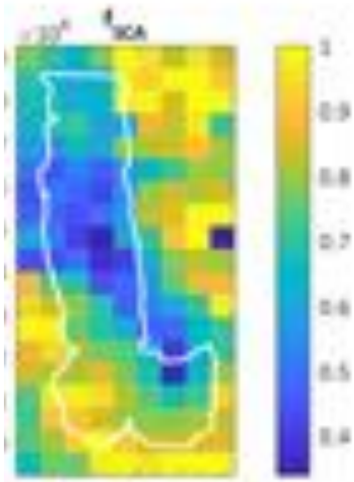
Graphic from Luke Flinn's 1996 draft EOS Volcanology Team report

Solution: While fSCA and local temperatures change rapidly in space, the median T's of trees and snow are very similar in adjacent cells



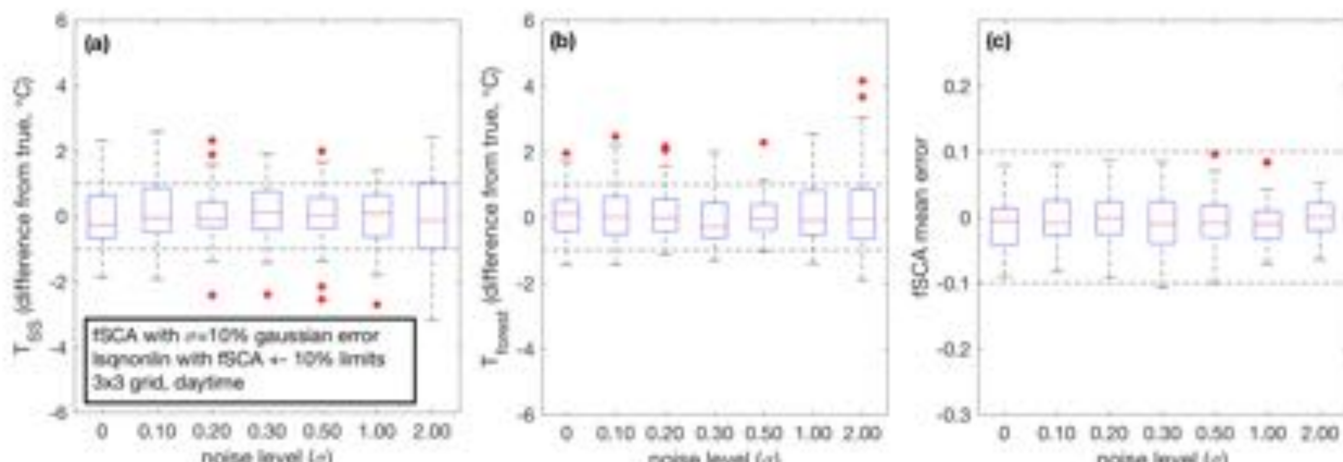
So, we take a 3 x 3 matrix of ~1 km cells, and solve for T_{snow}, T_{forest}, and 9 values of fSCA
(45 equations with 11 unknowns)

Day (credit to Jeff Dozier for idea and code):

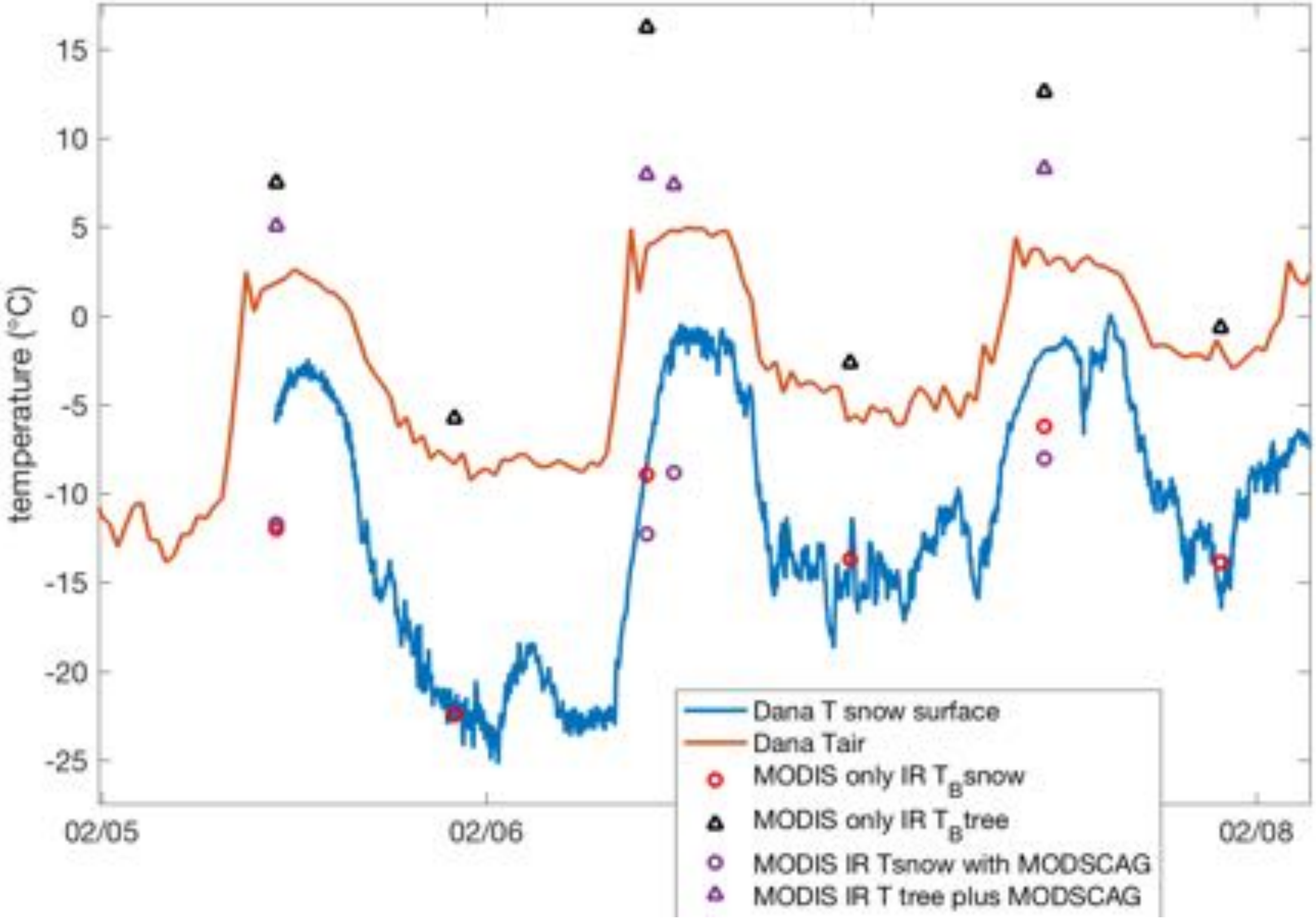


1) Take MODSCAG fSCA and reproject it to the MODIS Level 1B grid.
2) Use this fSCA and the solar angles relative to the surface (as well as surface solar radiation observations if available) to calculate the expected radiance from reflected sunlight in the midwave IR bands
3) Subtract this off observed midwave radiance
4) Proceed as before, using MODSCAG fSCA as first guess and limits to the fSCA fit

In idealized tests with imposed random errors, works to within 1 degree!



PRELIMINARY RESULTS



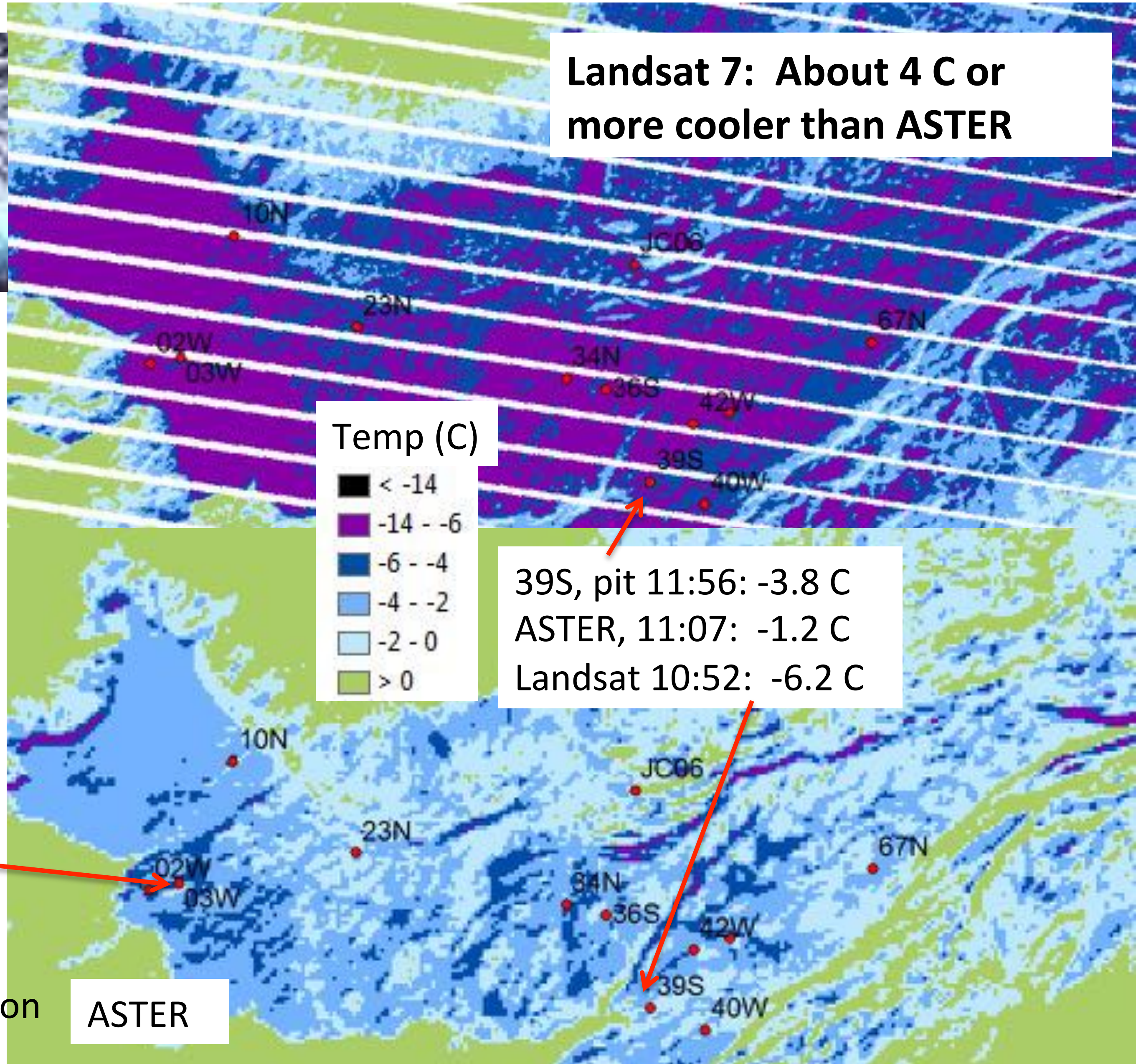
At night, we can separate Tsnow and Ttrees at 1 km scale and match surface Tsnow obs within ±1 C accuracy.

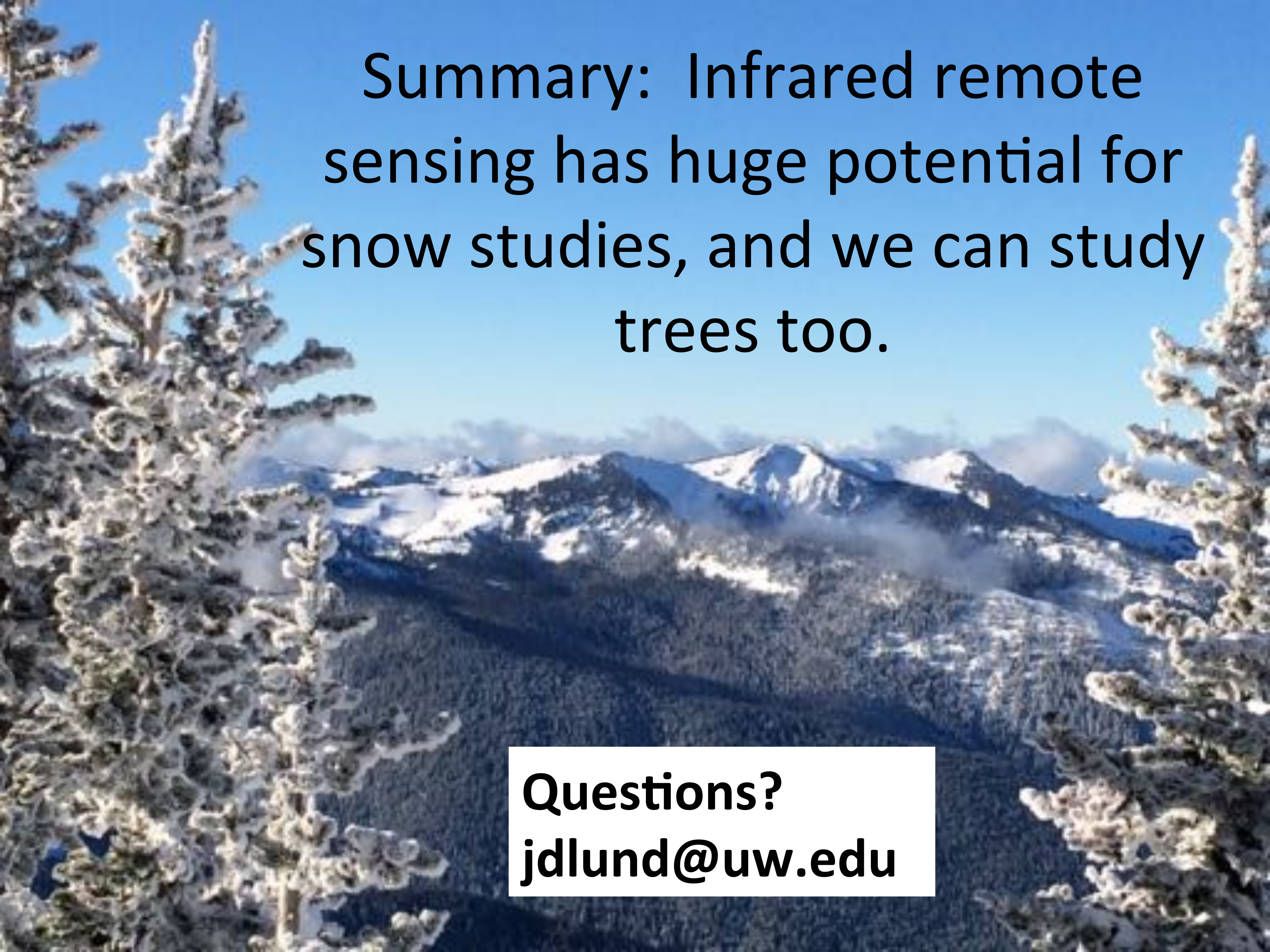
SnowEx: Grand Mesa, CO, 11 am Feb 15

Quick Look:
Much work to be done here!
We're excited about the tower and P3 data!

3W, pit 11:35 am: -4.7 C
ASTER 11:07 am: -4.2 C

Graphs by Hannah Hampson





Summary: Infrared remote sensing has huge potential for snow studies, and we can study trees too.

Questions?
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